

Promising practices that promote inclusivity at University-affiliated makerspaces within schools of engineering

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There are pockets of success around the nation where makerspaces have successfully reached a more diverse population, than the trending white and male nature of these spaces... However, these spaces are the exception and not the norm. And, little research has been done on these spaces to document what is working, how or why [1, p. 40].

Introduction

The maker movement and resulting makerspaces have permeated informal and formal learning spaces over the past decade. However, little work has been done to deepen the understanding of how inclusive these makerspaces are for engineering students from underrepresented groups. These makerspaces, physical spaces where people work on and complete making-related projects and activities, have the potential to create an open and inclusive community where exploration, creativity and collaboration are emphasized. While there is much potential with these makerspaces, we are concerned that these makerspaces may unfairly benefit students from privileged backgrounds, such as those who are white, male, cisgender, heterosexual, and from higher socioeconomic statuses.

Makerspaces support a multidisciplinary learning experience that seeks to create organic learning experiences for the participants. Within engineering education and society, the cultures surrounding makerspaces can enhance the relationship between informal and formal learning; improve teaching methods, evaluation, and assessment; and develop diversity, accessibility, and inclusion [2]. Thus, makerspaces have the potential to help all students incorporate both the practices and culture of engineering outside of traditional engineering classrooms. In this study, we are interested in uncovering promising practices that promote an inclusive environment in makerspaces. We are focusing on what makerspaces are doing well instead of what makerspaces are not doing so well and hope to inspire readers with practices that may work to increase inclusivity within their makerspaces and for engineering students. In this research, we seek to answer the following research question: What are promising practices for promoting inclusivity of engineering students from underrepresented groups in makerspaces?

Literature review

Makerspaces at universities. Given this connection between makerspaces and education, universities have incorporated makerspaces in their physical and curricula space. While makerspaces are a relatively recent development in engineering education, a 2014 survey of 127 highly ranked colleges and universities in the United States found that 40 have documentations of their institution's makerspace on their websites [3]. Makerspaces at universities are found within multiple disciplines (i.e., fine art departments, libraries, and science, technology, engineering, and math departments), occupy various physical space footprints and include multiple pieces of equipment. While there is no breakdown of the necessary equipment or specific facilities that compose a makerspace, components that the majority of engineering

departments are adopting include rapid prototyping tools, such as additive manufacturing machines (3D printers) and laser cutters [3], [4].

Makerspaces and Engineering Education. Makerspaces have become popular within engineering education. Integrating a makerspace into an engineering curriculum can be a daunting task given the scope and sequence of university engineering coursework. Recent research found that over a three-month period, students who took part in a course that integrated a class project within the makerspace were positively and significantly impacted in the domains of technology self-efficacy, innovation orientation, affect towards design, design self-efficacy, and belonging to the makerspace [5]. These shifts were found in students ranging from first-year students to fourth-year students and to students across many disciplines of engineering. This study found that the successful integration of a makerspace into an engineering curriculum requires an asset-based approach coupled with realistic learning outcomes.

When looking at specific skills related to engineering makerspaces, these skills can serve as catalysts to innovation, confidence and design [6], [7]. Within engineering education and society, the cultures surrounding makerspace could enhance the relationship between informal and formal learning; improve teaching methods, evaluation, and assessment; and develop diversity, accessibility, and inclusion [2]. Inclusion is about “teaching all students in [the classroom], not just those who are already engaged, already participating, and perhaps already know the [content] being taught” [8, p. 322]. Thus, makerspaces have the potential to help all students incorporate both the practices and culture of engineering outside of the traditional engineering classroom.

Creating Inclusive Makerspaces. Most critical examinations of makerspaces are in the K-12 space; those in university spaces are about the processes of making rather than the pedagogy that supports making [1], [9]. Within K-12 education, the findings are clear that these spaces can support opportunities to engage in STEM content as well as design, innovation, and STEM identity development. For example, in a study of a 10-week project in K-12 makerspace, Fasso and Knight [9] found that the constant negotiation and collaboration required to complete a project within the makerspace provide a sociocultural space to support identity development. In higher education settings, Carbonnel, Andrews, Boklage, and Borrego found that a semester-long project which required the use of an engineering makerspace increased students’ technology and design self-efficacy, affect towards design, innovation orientation, as well as their sense of belonging in a makerspace [5]. In addition, in research that has emerged from this larger research study, Greene, Kellam, and Coley found that while makerspaces overall promoted agency and engineering identity for Black male undergraduates, makerspaces at PWIs reflected the heteronormative culture of engineering [10]. This heteronormative culture resulted in Black men not realizing their agency and development of their engineering identity as well as other Black men who engaged in the makerspaces at a Minority Serving Institution (MSI). Lam, Cruz, Kellam, and Coley found that female students perceived gender bias within the makerspaces that, in some cases, resulted in an intimidating, hostile, and non-inclusive environment [11]. Even in spite of these negative findings, some female students also experienced increased confidence and learning opportunities when engaging in makerspaces. Finally, Jennings, Coley, Boklage, and Kellam analyzed student’s recommendations for improving makerspaces and, interestingly,

found that men tended to recommend equipment and technology improvements in the makerspaces, while women tended to recommend social change in makerspaces [12].

More recently, Vossoughi, Hooper, and Escudé articulated the importance of foregrounding equity when researching makerspaces. This work situates making within the lens of culture and power [13]. Vossoughi and colleagues found that, “while a number of researchers celebrate the range of identities, practices, and learning environments made available through making, less attention has been paid to the measures of valuable human and educational activity reproduced by the movement in its current form and their consequences for equity-oriented pedagogy and research” [13, p. 213]. They emphasized the importance of critically examining what we count as making (e.g., is knitting included alongside 3D printing?) and argued that “close attention to who students are- and what they are experiencing as cultural, historical, and political actors-alters and shapes the pedagogical design and practices of making in consequential ways” [13, p. 215]. Vossoughi and colleagues called for explicit attention to our philosophies and practices embedded in our pedagogies and to situate our efforts in a deep understanding of learning as embedded within cultural activities and as crucial in challenging rather than reproducing deficit ideologies.

Theoretical Framework

In this study, we are interested in identifying promising practices within makerspaces so that a more inclusive environment in makerspace can be promoted. We are intentionally not using the term “best” practices as this term suggests that there is a single, correct way to create an inclusive makerspace. In addition, the term best practices implies that context does not matter and that a practice can simply be transferred into a new context and still remain the “best” [14]. Best practices can lead towards more overgeneralization and that is not our intention in this paper. Instead, we encourage the readers to read through these promising practices while considering their specific contexts and hopefully find some inspiration in these practices. In the research design that we describe below, we are, in essence, answering the research question: which practices did we observe or learn about that are promising in creating a more inclusive makerspace? Thus, we frame this paper as uncovering promising practices for increasing inclusivity in makerspaces in the context of engineering education. This is an important contribution as it explicitly bridges our larger research project to practices, thus not only situating us to learn about inclusivity in makerspaces that engineering students engage within, but also to have some impact on practices with what we have learned through our extensive data collection efforts.

Research Design

In this research project, we observed ten makerspaces at seven universities in the US. The seven universities that we visited ranged in size from 2,000 students to over 50,000 students, ranged in their US region, ranged in their classification category, and represented both MSIs and primarily white institutions (PWI). The MSI’s included one Historically Black College and University (HBCU), one Asian American Native American Pacific Islander Serving Institution (AANAPI), and one Hispanic Serving Institution (HSI). Each institution was given a pseudonym. More details about each of these institutions is included in Table 1. At each makerspace, we made

observations, interviewed management or directors of each space, and interviewed students, with a focus on students from underrepresented groups. In total, we had at least four written observations from each makerspace (field notes), photos from each space, six audio-recorded interviews with makerspace management, field notes written after observations and tours of makerspaces led by makerspace management, and interviews with 67 engineering students who also use the makerspace.

Table 1. Institutional information, Bacc.=Baccalaureate, Doct.=Doctoral, Mount.=Mountain

Institution Pseudonym	South Atlantic Univ.	New England Univ.	Pacific Univ.	Gulf Univ.	Mount. Univ.	Middle Atlantic Univ.	South Central
Census Region	South Atlantic	New England	Pacific	West South Central	Mount.	Middle Atlantic	South Central
Control	Private	Private	Public	Public	Public	Private	Public
Population	~2k	~11k	~20k	~37k	~4k	~4k	~51k
Classification Category	Bacc. College	Doct. Univ.	Doct. Univ.	Doct. Univ.	Doct. Univ.	Bacc. College	Doct. Univ.
PWI/MSI	MSI- HBCU	PWI	MSI- AANAPI	MSI- HSI	PWI	PWI	PWI
Makerspace Management Model/Type and Access	Staff and student led/Engr. only with limited access	Student led/Open	Faculty presence, student led/Engr. only with limited access	Student tech led/Open	Staff and student tech led/Open	Faculty, staff and student techs/Open	Faculty, staff and student techs/Engr. Only

Data Analysis. Immediately after each site visit, we had audio files transcribed through the service rev.com. After the transcription was completed and checked by a member of our research team, we then coded these data using the following a priori codes: Practices that may promote inclusivity and practices that may promote marginalization (See Table 2). The focus for this paper is the practices that may promote inclusivity.

Table 2. Codebook with descriptions and exemplar quotes

Code	Description	Exemplar Quote
Practices that may promote inclusivity	These are practices that are observed, that students	I am a department chair, faculty, so a lot of that culture is invisible to us. We hire techs in the makerspace who are here. I think

	describe, or that faculty describe that may promote a sense of belonging and identity development of engineering students within the makerspace	we've tried to create some opportunities for underrepresented students, try to give them a chance to maybe earn some money, be in this space.
Practices that may promote marginalization	These are practices that are observed, that students describe, or that faculty describe that may promote engineering students feeling oppressed or marginalized	I had one bad experience, and this is something that I generally try to avoid doing myself, even if it's accidentally, but I remember one day, last semester, it was towards the end of semester, I finally had time to come here whenever. There were a few upperclassmen that were in here, and it's almost like try to keep it a secret. That there is a makerspace space. They try to be like, "Oh, well, this is ours." ...Because, they really try to shield it. They try not to talk about it, like, "Oh, it's all our little hideout," but I feel like it's counterproductive because it's obviously the more people that join the makerspace, the more attention it gets, the more equipment we get.

After this initial pass of coding, we identified specific promising practices for promoting inclusivity within the makerspace. The following codes on promising practices emerged: Increasing visibility; integrating the makerspace throughout the curriculum; encouraging interdisciplinary collaborations; culturally relevant making; deliberately designing space to encourage collaboration; promoting inclusivity through the physical space; fostering a risk-taking, fail-forward culture; increasing accessibility for students with different abilities; increasing accessibility through time that the space is open; and hiring student techs to develop a sense of belonging and encourage inclusivity. These promising practices will each be discussed more specifically in the findings section.

Findings

The findings focus on promising practices in the makerspaces. At the end of each promising practice, we include some questions to consider that may inspire promising practices when trying to create a more inclusive makerspace.

Increasing visibility. Makerspaces at South Central and Middle Atlantic did a good job of showcasing their makerspaces and increasing the visibility of their makerspaces to both prospective students and local industries. For example, at Middle Atlantic, students created a large sign for the makerspace. At South Central, the makerspace was featured in a commercial during a college football game on the jumbotron. Alternatively, some makerspaces had no signs

and students could pass by the makerspace without knowing that the makerspace existed. Increasing the visibility of the space through signage that can be created within the makerspace could encourage more student engagement in the space, and, subsequently, support for the space.

Another way that Middle Atlantic management described increasing visibility of the makerspaces was through encouraging students to become ambassadors for the space.

There was a student, I guess he's still here, Richie, who I think was in the college of engineering and he switched, he's been arts and sciences now, but he's been awesome because he'll take these classes in the college of arts and sciences and then he'll email me and he'll say hey, this professor is awesome in music, can I send him over to you? I'd say yeah, great, bring him over. I've met with three or four professors who the student has sent over here. It's been great, they've come over, we've probably chatted for an hour, we've talked about the space and ideas I've had and things that could go on in here.

Some questions to consider for your makerspace:

- How can we increase the visibility of our makerspace?
- How do people learn about the makerspace?
- How do we encourage first-timers to engage in the makerspace?
- What signage does the makerspace have?
- Who are our ambassadors in the space and how can we encourage them to spread the word about the makerspace?

Integrating the makerspace throughout the curriculum. Mountain University has a strong integration of making throughout the curriculum. This is, in part, because of the design spine in the curriculum, where students take a design course each semester of their four-year curriculum. Many of the projects in the design spine require prototyping and presentation of a final design at a showcase at the end of the semester. In the first semester, first year design course, students are required to be trained on equipment and to use equipment, for example the 3D printer and laser cutter, for projects. In addition, some of the engineering science course faculty have begun integrating making projects into courses. This curriculum integration helps build student awareness of the space and increases the use of the space, which can be used to leverage more institutional resources.

A question to consider for your makerspace:

- How can we integrate the makerspace into the curriculum?

Encouraging interdisciplinary collaborations. At South Atlantic University, the makerspace had faculty from across campus use the space and develop workshops for students, staff, and faculty. For example, they had a faculty member from African studies develop workshops in the space. The makerspace director explains this faculty member's excitement about the space, "He's a new faculty member. When he heard we had a makerspace he was like, 'We've got to do some stuff.'" Drawing interdisciplinary faculty into the makerspace, could be a catalyst for the creation of innovative workshops. This faculty member held workshops on making a talking drum and

then another with music majors where they made an electric synthesizer with a steering wheel and entered a competition.

Some questions to consider for your makerspace:

- How can we encourage interdisciplinary projects within the makerspace?
- How can we engage interdisciplinary students and faculty in the space?

Culturally relevant making. At South Atlantic, an HBCU, they have implemented culturally relevant making projects. This has involved interdisciplinary teams of faculty, students, and staff who have worked to create African instruments, for example, a kalimba, using tools such as a laser cutter in the makerspace. These culturally relevant making projects were organized through weekend-long workshops that students and staff could attend, a summer program, guest lectures, and a performance in which the created kalimbas were used. This multi-faceted approach to integrate culturally relevant making on campus was an exemplar way of increasing visibility for the makerspace, and, hopefully, helping encourage more support of the makerspace by administrators, other faculty, and staff. The makerspace administrator explained how this interdisciplinary project helped bring visibility and administrative support to the makerspace,

Most students probably still don't even know what the makerspace [is] or that it does exist. More people do now than they did two years ago, three years ago. With the kalimbas, with the faculty starting to introduce it. That's why the school has gotten to the point of saying, we're going to go ahead and invest in this.

Additionally, developing culturally relevant making projects can serve as a way to explicitly encourage more students from underrepresented groups to engage in the makerspace.

Some questions to consider for your makerspace:

- How can we integrate culturally relevant projects into the makerspace?
- What other ways can we showcase the work from the makerspace (e.g., through summer programs, guest lectures, performances)?

Deliberately designing space to encourage collaboration. At South Central, a PhD granting PWI, the makerspace manager continuously explored ways to cultivate more interactions among students. As an example of this, he did not allow students to have their backpacks in common spaces, including on tables or chairs. Instead, he created cubbies for students to store their bags and only allowed the students to have what they are working on with them at the open tables. The manager required this because having a backpack on the table beside a student would keep another student from sitting in that space. The manager was trying to identify and remove barriers for students to interact more with one another. This is an example of a low cost, but potentially large impact way of increasing collaboration within the space.

In these spaces, there is often a mixture of students working on homework or making projects. Such mixed use of the space can foster collaborations and develop a sense of community. In many of our observations at multiple universities, we observed these multiple uses of the space. At South Central, the manager of the space explained that when they first opened the space, they had equipment on tables throughout. After some time watching students using the space and

talking with these students, the manager learned that the students preferred open tables which were more flexible in their use. The management team then moved the 3D printers and equipment to the outer parts of the space so that they could open up some tables in the center of the space for the students. Similarly, at Middle Atlantic University, a private PWI, the makerspace manager echoed the importance of the open space and having more room for students to gather together,

One of the things that was pretty clear is that the space actually matters. If people don't have a space they can gather, it's really hard to build community. One of the things I came in really sensitive to, having done it before, is how do you build spaces students want to be in, and that don't have the rigid, hierarchical interactions? It's not a lab space and you show up for your three hours and there's somebody in charge of it, but really a space that you can come and go to begin to, over probably a decade, start to shift the culture.

Some questions to consider for your makerspace:

- How can we encourage collaboration in the space?
- Does the physical environment encourage or limit collaboration?
- How can we arrange the space to encourage more collaboration?
- How can we create spaces students want to be in?

Promoting inclusivity through the physical space. At Middle Atlantic University, a private institution, the management deliberately selected posters to decorate the makerspace with Brene Brown quotes (see <https://shopzenpencils.com/collections/posters/products/brene-brown-the-woman-in-the-arena> for an example). A manager from Middle Atlantic University, described the reasons for including these posters within the makerspace.

You go into so many labs and you see a poster of the magnetic spectrum or the inside of a chip or something, and we were sensitive to stereotype threat and how that might make people feel. There's a comic strip I read call Zen Pencils, the guy takes inspirational quotes, he's a Malaysian cartoonist and turns them into these inspirational cartoons, and so we have those up around the walls, and we've been very careful to try to make the space as social as possible, kind of a multipurpose space, and not make it the weird, smelly tech place to go, at least for the culture.

Conversely, in another makerspace that was a part of Mountain University, there were primarily posters with images of white men working on entrepreneurial projects within the space. The exception to that was a single poster with a Latina woman showcasing her cupcake toppers business. Consideration of, for example, a student walking into the makerspace for the first time and their initial impression of the space could lead to stereotype threat as the manager at Middle Atlantic University explained above.

Some questions to consider for your makerspace:

- What does a person entering the makerspace for the first time see?
- How do we highlight student's projects in the space? Are we highlighting diverse students?

- How do our marketing materials reinforce gender or racial biases?

Fostering a risk-taking, fail-forward culture. South Central has a well-funded and supported makerspace and students can use materials for free. Each student gets a certain allotment of materials each semester. This encourages students to take risks in their projects, risks that some would not take because of the need to pay for those mistakes. While this model will only work for well-funded institutional makerspaces, it will not work for most. However, it could be possible to reduce material costs for students through bulk pricing, and by reducing material costs students may engage in more risk-taking with their projects, and develop more expertise using the equipment in the space.

Some questions to consider for your makerspace:

- How can we encourage students to take risks in the makerspace?
- How can we lower costs associated with the makerspace?
- How can we decrease material costs for students?

Increasing accessibility for students with different abilities. An area for improvement for all of the makerspaces was increasing accessibility of the spaces for students with disabilities. For example, during one of our observations at Mountain University, we observed two students lifting a student in a wheelchair so that he could see his work in the laser as it was being cut. Having lifts or putting a laser on a lower table could enable access by differently abled individuals.

Some questions to consider for your makerspace:

- How can we increase the accessibility of our makerspace?
- How can students with physical disabilities engage meaningfully in the space?

Increasing accessibility through time that the space is open. In addition, some makerspaces had very limited hours (e.g., from noon to 5) and thus did not work well with student's free time. By shifting that time to 5 to 10pm, there may be more students who can engage in projects in the space. This would be context-specific, but could impact the number of students who engage in the space.

Some questions to consider for your makerspace:

- Is the makerspace open during hours that align best with student availability?
- When are the high use hours of the space? How can we increase the open hours during these times?
- Can we have student volunteers oversee the space during hours that are typically closed?

Hiring student techs and staff to develop a sense of belonging and encourage inclusivity.

There were many exemplary illustrations of this promising practice. For example, at both Middle Atlantic University and South Central, the management intentionally hired students from underrepresented groups and trained students to welcome students to the space, help train them on equipment, and help them advance their projects. Students from these institutions discussed feeling supported by all of the staff in the makerspace. In a few instances of bias and prejudice, it was from other users of the space when there were no staff present. The management and faculty

were critical to aligning the practices of the space with the vision that they were enacting. Finally, while we did not observe this, it may be beneficial to have staff training around diversity, equity, and inclusion. This training could help mitigate intimidation barriers and help management and student techs to think more purposefully about inclusivity and ways of dealing with instances of bias that they may encounter in the makerspace.

Below is a quote from New England University that explains the value that they put into hiring undergraduates to work in the makerspace and how those students influence the culture.

Student-run makerspaces are very important. We've found that the student model, where the students are doing the actual training, is an important aspect, because students learn better from other students. Students are more willing to approach another student, even if it's an undergraduate to a graduate student, than to say, a 40-year-old technician in a shop. They're more willing to ask questions and seek that out. Then they have more fun also, in sharing that knowledge. The students who are passionate about making, it's not just their personal experience with it. They want to share that. They need the opportunity to teach other students how to do things, show them from their own mistakes and mistakes they've watched others make, how to avoid making those mistakes so they can make new mistakes, is an important thing.

Some questions to consider for your makerspace:

- Who is working in the makerspace? In what ways are the staff diverse in their backgrounds and identities?
- How are your staff encouraging the development of a sense of belonging among makers?

Discussion

Through our interviews with students and makerspace managers, we are trying to develop a critical understanding of makerspaces and what it means to create an inclusive makerspace. Using a critical theory lens [15] encourages us to move beyond individual students and staff's experiences and perspectives to consider structures that contribute to equalities and inequalities within the makerspaces.

Changing engineering cultures to become more inclusive can be very daunting. Marginalization and oppression occur throughout engineering undergraduate student's experiences. However, makerspaces are a relatively recent addition to engineering programs. In this work, we uncover promising practices that we learned about while conducting a research project at eight universities. Our hope is that this work can help managers and directors of makerspaces in higher education create more inclusive makerspaces. In our work, we have found that engaging in makerspaces promotes agency and engineering identity for Black male undergraduates [10] and increased confidence and opportunities to learn for female undergraduate students [11]. In addition, we found that the recommendations that students make for improving makerspaces differ as women and men who belong to underrepresented groups tend to suggest more social changes and majority men request more equipment [12]. In this paper, we have identified some

of the promising practices that were identified in this broader work. These promising practices could help us create makerspaces that are more inclusive.

In imagining an inclusive makerspace, it is helpful to think about students and how they learn about and first enter the engineering space. This can be improved by increasing the visibility of the makerspace and integrating the makerspace and making throughout the curriculum. It can also be helpful to encourage interdisciplinary collaborations so that more students and faculty learn about the space and to consider integrating culturally relevant making projects and workshops into the makerspace. Another consideration when attempting to create inclusive makerspaces is to consider the physical space. Something as simple as posters and marketing materials that highlight diverse students could help promote a more inclusive space. In addition, the setup of the space can be modified to encourage more collaboration through, for example, providing open, flexible-use tables so that students can collaborate easily in the space. Also, policies can be set up in the space to encourage more collaboration. The accessibility of the space is also important to consider through questions such as the following: Are all students able to access the space? Are the hours that the space is open aligned with students' schedules? Finally, how can policies be developed that encourage more inclusivity. These can include policies around hiring practices, training of staff, and availability of materials at low or no cost to encourage experimentation in the makerspace.

In addition, when visiting these makerspaces, we learned that the context of each of these makerspaces was very unique. For example, some makerspaces had significant financial support from the university and college of engineering, while others were bootstrapped by a single faculty or administrator. Through this paper, we hope that we have provided some ideas and questions that help spark new ideas to improve the inclusivity of a makerspace within your specific context.

Conclusion

A primary goal of this research was to bridge our findings to practice with the purpose of providing promising practices for creating and sustaining inclusive makerspaces to the broader community. Inclusion is about “teaching all students in [the] classroom, not just those who are already engaged, already participating, and perhaps already know the [content] being taught” [8, p. 322]. Our findings indicate that the physical space, the culture and the staff are integral to creating an inclusive makerspace. By focusing on these aspects of makerspaces (physical space, culture, and staff), we can cultivate a sense of belonging for the students, from the location on campus, to the posters on the wall to the organization of the furniture, so that students can have a sense of belonging in the space [16], [17] and identify themselves and their peers as engineers regardless of their backgrounds [18]. Incorporating the makerspace into the engineering curriculum could increase student's chances of engaging regularly in the makerspace and help them realize that the space is open and welcoming. Furthermore, if we (including student workers, staff, and faculty working in makerspaces) make explicit attempts to support a risk-taking, fail-forward culture, students will begin to feel as if they can learn in the space and that it is a space in which they do not have to arrive knowing all of the answers.

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